# New viviparid gastropods from the end Cretaceous and early Paleogene of the Williston Basin, USA and Canada

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## ABSTRACT

Three new species of Viviparidae (Caenogastropoda) are described and illustrated from the Williston Basin of North Dakota, Montana, and Saskatchewan. The new *Campeloma*, with strong shoulder development, is separated from others in geologic time by recognizing its distinctive morphological features. *Campeloma acroterion* new species occurs primarily in Lancian North American Land-Mammal Age (NALMA) strata, survives the Cretaceous–Paleogene extinction event, and ranges into the late Puercan NALMA (end Cretaceous to lower Paleocene; Hell Creek Formation into Tullock Member of Fort Union Formation and equivalents). *Campeloma nebrascense whitei*, a larger and more rounded, but shouldered species, appears as a derivative species in younger rocks, followed and partially coeval with *C. n. nebrascense*, which is without shouldering. *Viviparus purgatorius* new species and *V. codomorphus* new species are species of discovery. Neither species are common and the few specimens collected have been assigned to more common taxa. *Viviparus purgatorius* ranges from the Puercan to Torrejonian (lower and middle Paleocene; Tullock Member and Ravenscrag Formation), and *V. codomorphus* may be only known from the Torrejonian NALMA (middle Paleocene; upper part of the Ludlow Member of the Fort Union). These species of *Viviparus* appear derived from more sculptured forms of *V. thompsoni* also present in Lancian strata of the Lance and Hell Creek Formations. With the regression of the Cannonball Sea and the expansion of Laramidia in the early late Paleocene, viviparids radiate, becoming far more numerous, diverse, and morphologically variable until the end of the Laramide Orogeny (~mid Eocene) with North America as one continental landmass.

## INTRODUCTION

This paper introduces new viviparid species that have been recognized by the author for some time (Hartman, 1984). Publication of a monograph on fossil Viviparidae is under construction, but still too far off to delay naming of a number of taxa. The continental molluscan record of the Cretaceous and Paleocene of Laramidia is more diverse than typically known. Three new viviparid species add to the known species richness during intervals of geologic time that are, in part, less populated by gastropods. These species are also in chronostratigraphic succession in the Williston Basin of North Dakota, Montana, and Saskatchewan. They include *Campeloma acroterion* (Lancian into Puercan NALMA), *Viviparus purgatorius* (Puercan into Torrejonian NALMA), and *Viviparus codomorphus* (Torrejonian into Tiffanian NALMA), ranging from latest Cretaceous to early late Paleocene (Maastrichtian to Selandian). These species occur in the Hell Creek Formation, and Tullock, Ludlow, and Tongue River Members of the Fort Union Formation in the United States, and the Ravenscrag Formation in Canada (Figure 1).

## MATERIALS AND METHODS

The taxa introduced are based on examination of fossils from more than 1100 continental molluscan localities (see Appendix 1; e.g., Hartman, 1984, Appendix 3, locality register; Hartman, 1998, fossil localities; Hartman and Roth, 1998, Appendix, Bighorn Basin locality register). This effort originally comprised the dissertation studies of the author (Hartman, 1984), but now includes many years of subsequent field and museum studies (e.g., Hartman, 1989, 2004; Hartman and Kihm, 1992; Hartman and Roth, 1998; Hunter et al., 1997; Hartman and Kirtland, 2002; Scholz and Hartman, 2007; Hartman et al., 2014). Many of the specimens examined were collected by others (e.g., Saskatchewan record) and are deposited at institutions (see list under Abbreviations) visited by the author. Important primary documentation was available for many localities at institutional archives. When possible, specimens were borrowed for additional study to compare with in-house specimens. In addition, several thousand photographs were taken of museum specimens to augment the borrowed material, and for use in measuring specimens. Only a few measurements of Cretaceous or Paleogene continental mollusks were available from the literature. Most of these measurements are in reference to types, and do not provide a

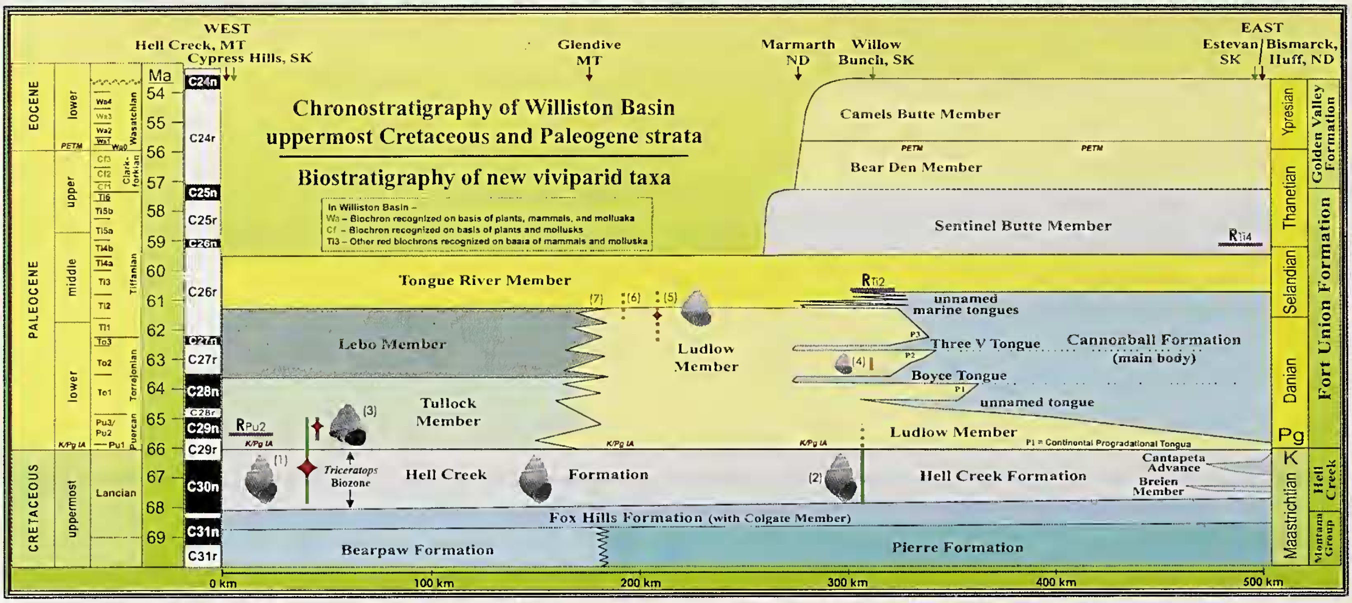


**Figure 1.** Chronostratigraphic placement of new viviparid species in a chronostratigraphic correlation of Williston Basin uppermost Cretaceous and lower Paleogene strata. Chart based on Lund et al. (2002), Hartman et al. (2005) and is revised using geochronologic and other data from Murphy et al. (2002), Clechenko et al. (2007), Secord (2008), LeCain et al. (2014), Ogg et al. (2014), Vandenberghe et al. (2014).

basis for a quantitative analysis of shell form, plus the methods by which the measurements were taken are virtually always unknown (e.g., specimen orientation; see measurement methods below). One of the purposes in redescribing previously named taxa (Hartman, 1984) was to provide a more rigorous quantitative database upon which to compare fossil viviparid morphologies. The quantitative measurement parameters used here to describe the introduced species (summarized in later tables) are used in diagnoses, descriptions, tables, and graphs in the systematic part of this report (and Hartman, 1984). Measurement types (and their abbreviations) are given in Table 1. Measurement parameters are illustrated in Figure 2. Individual shell measurements are given in Appendix 2.

**Abbreviations and Notes:** W = number of whorls; SD = standard deviation; min. = minimum; max. = maximum; n = number of specimens; loc. = number of localities. K/Pg = Cretaceous–Paleogene, La = Lancian, Pu = Puercan, To = Torrejonian, Ti = Tiffanian, Cf = Clarkforkian, Wa = Wasatchian, NALMA = North American Land-Mammal “Ages.” HC = Hell Creek, LA = Lance, LU = Ludlow, TU = Tullock, LE = Lebo, TR = Tongue River, FU = Fort Union, RA = Ravenscrag. AMNH-FI = American Museum of Natural History, Fossil Invertebrates, New York; GSC = Geological Survey of Canada, Ottawa; MCZ = Museum of Comparative Zoology (Harvard University), Cambridge; UND-PC = University of North Dakota, Paleontological Collection, Grand Forks; UND-JHH = Hartman collection at UND; UCMP = University of California Museum of Paleontology, Berkeley; UMPC = University of Minnesota, Paleontological Collection, Minneapolis; USNM-PAL = U.S.

**Table 1.** Measurement Abbreviations.

| Measure | Description/How Measured (see Fig. 2) |
|---|---|
| #W | Number of whorls or revolutions; counted on complete specimen |
| #W-MHI | Number of whorls; counted on maximum height of a slightly incomplete specimen |
| #W-MS | Number of whorls; counted on an incomplete specimen (MS = maximum seen) |
| MSA | Mean spire angle |
| MHI | Maximum shell height; measured with hand calipers or right lateral view |
| PWI(MWI) | Width measured from photograph; measured with calipers |
| PHI | Height; measured from photograph |
| PSH1 | Spire height; measured from photograph |
| PSH2(MSH) | Spire height 2 = mean spire height; measured from photograph |
| PBH | Body height = last-whorl height; measured from photograph |
| PSW1(MSW) | Spire width 1 = mean spire width; measured from photograph |
| PSW2 | Spire width 2; measured from photograph |
| PAW | Aperture width; measured from photograph in plane of axis of coiling |
| PAH | Aperture height; measured from photograph in plane of axis coiling |
| FAW | Flush aperture width; measured from photograph in plane of aperture |
| FAH | Flush aperture height; measured from photograph in plane of aperture |
| GLA | Growth-line angle; measured in right lateral view from photograph |
| MSW/MSH | Ratio approximates mean spire angle |
| MSW/PSW2 | Ratio = last-whorl expansion ratio |

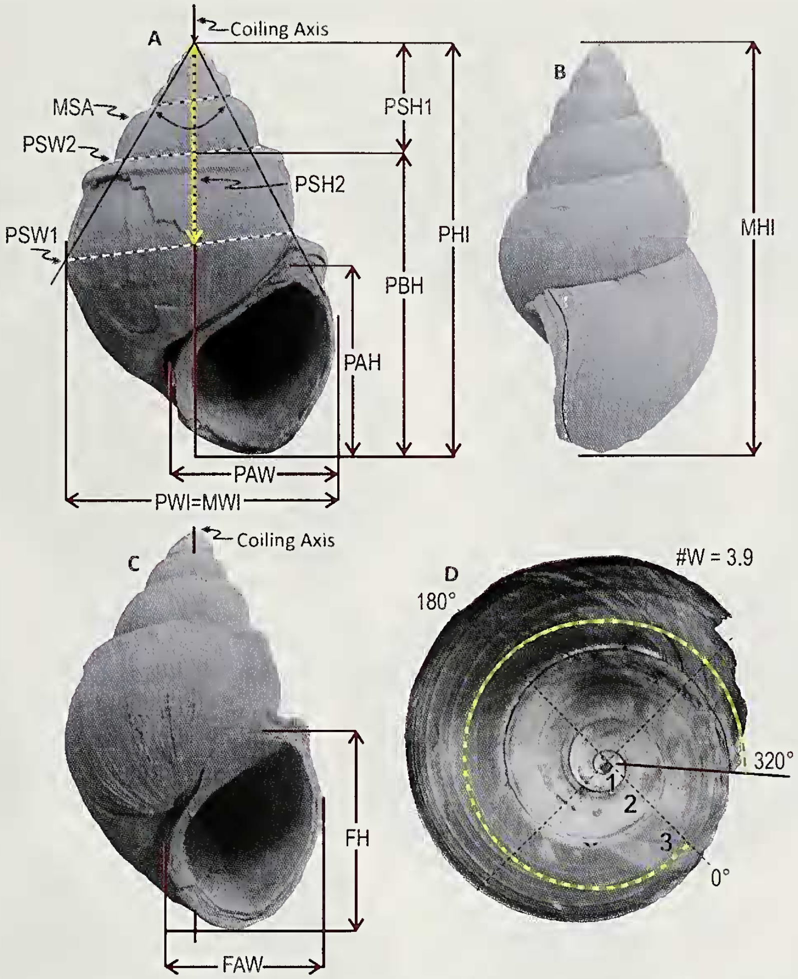


**Figure 2.** Gastropod Measurement Abbreviations. Figures 2A–D represent three standard photographic views from which specimen measurements were acquired (see Table 1 for abbreviations). **2A.** Apertural. **2B.** Right lateral, growth-line angle (GLA) is vertical (one-dashed line) in species of *Campeloma*. **2C.** Apertural flush. **2D.** Apical, number of whorls (revolutions) counted with use of a protractor. **2A** and **2C.** *Campeloma acroterion*. **2B.** *C. nebrascense nebrascense*. **2D.** *Viviparus purgatorius*.

National Museum of Natural History, Invertebrate Paleontology Collection, Washington, D.C. See also abbreviations in Appendix 1 (Locality Register).

All United States quadrangles are USGS 7.5-minute, 1:24,000, topographic maps, NAD27CONUS datum, with 20 ft (6.1 m) contour intervals. All Canadian maps are Natural Resources Canada (was Department of Energy, Mines and Resources), 15×30 minute, 1:50,000, topographic maps, NAD27 datum, with 25 ft (7.6 m) contour intervals.

Two **Appendices** with **supplementary data** to this work are posted online at http://nautilus.shellmuseum.org. **Appendix 1** is a Locality Register describing in detail the localities discussed herein. **Appendix 2** consists of three tables with measurements of all specimens of the three species presented in this study.

## Explanation of Figure 1

The correlation of strata presented in Figure 1 uses a Hell Creek Formation duration of 1.8 million years (Wilson, 2005). Although no single value can be correct, the Fox Hills Formation in the western part of the Williston Basin is approximated as the top of the *Jeletzkytes nebrascensis* ammonoid zone (Landman et al., 2007; Vandenberghe et al., 2014). PETM (= Paleocene-Eocene Thermal Maximum) and the K/Pg IA (= Cretaceous–Paleogene Iridium Anomaly, or similar evidence, e.g., fern spike) are located approximately along a transect from Bismarck to Marmarth (see Hartman et al., 2002, for citations; Clechenko et al., 2007; Hartman et al., 2014). The approximate locations and biohorizons of type localities in Figure 1 are indicated by "?" on vertical local biostratigraphic range lines. RPu2 (= Ravenscrag Formation, Puercan 2, etc.) symbols are overlays of the approximate NALMA known or interpreted from the Ravenscrag Formation in the Cypress Hills of southernmost Saskatchewan (see text). Figure 1 notes include: 1) *Campeloma acroterion* is described from the uppermost Cretaceous Hell Creek Formation in its type area of Hell Creek (Table 3), north of Jordan, Montana. *C. acroterion* is also known from the lowermost Paleocene

Tullock Member (Fort Union Formation) in the western part of the Williston Basin. 2) *C. acroterion* is not well known from the lowermost Paleocene of easternmost Montana or North Dakota. *C. acroterion* is known from a number of other uppermost Cretaceous formations in the USA and Canada. 3) *Viviparus purgatorius* is described from the lowermost Paleocene Tullock Member in McCone County, Montana (see Table 7). *V. purgatorius* is also known from the Bear Member (Fort Union Formation) in the Crazy Mountains Basin, Montana, and from the lower part of the Ravenscrag Formation in Saskatchewan. 4) *V. codomorphus* is described from the Ludlow Member (Fort Union Formation) between the tongues of the Boyce and Three V Tongues of the Cannonball Formation in the Little Missouri River valley, Slope County, North Dakota. 5) The type locality of *V. codomorphus* is from the east flank of the Cedar Creek Anticline in what the author interprets as uppermost part of the Ludlow Member in easternmost Montana. 6) *V. codomorphus* also occur at an ill-defined location in the vicinity of Wibaux, Wibaux County, Montana. This occurrence might place it in the Tongue River Member. 7) The Ekalaka Member (Fort Union Formation) does not occur between the Ludlow and Tongue River Members (Fort Union Formation) along the traverse of this profile (see Vuke et al., 2007).

## STRATIGRAPHY

The litho- and chronostratigraphy of the Cretaceous–Paleogene boundary-interval strata in the northern Great Plains and intermontane basins of the United States and Canada are subjects of continual refinement (see citations above and Figure 1). Field notes and other unpublished information were used to augment collection and/or published accounts of species records to better geographically plot and place specimens in relative stratigraphic position. All type localities were examined by the author, with the help of others, on more than one occasion. Stratigraphic and sedimentologic data were collected along with other elements of the local fauna. The three taxa described are presented in stratigraphic succession. *Campeloma acroterion* is known primarily from the uppermost Cretaceous Hell Creek and Lance Formations and also from formational equivalents. It also is one of the few species in the northern Great Plains known to cross the K/Pg boundary, with occurrences in the Tullock Member of the Fort Union Formation. *Viviparus purgatorius* is primarily known from localities in the Tullock Member and is well documented from the lower and middle part of the Ravenscrag Formation in Saskatchewan. The stratigraphic horizon of the type series of *V. codomorphus* is the least well documented, in occurring at the top of a large, grass-covered hill on the flank of an anticline. Vuke et al. (2003) mapped this silcrete-bearing section as Tongue River Member, but previously mapped the area as equivalent to the upper Ludlow Member (Vuke et al., 1986). The author is inclined to map it as Ludlow Member (see later discussion below and with Figure 1). In North Dakota, *V. codomorphus* occurs between the Boyce and Three V Tongues of the Cannonball Formation in the upper part of the Ludlow Member (above the T Cross lignite of Moore, and below the silcrete horizon at the top of the member [Hartman, 1993]).

A NALMA can be interpreted for each species. The holotype of *Campeloma acroterion* is Lancian and ranges to Puercan 2–3 (Figure 1, note 1). The species duration is estimated to be about 3 million years. The holotype of *Viviparus purgatorius* is Puercan 2–3 and likely ranges to mid Torrejonian (Figure 1, note 3). The duration of the species is also estimated to be about 3 million years. The holotype of *V. codomorphus*, if the specimens are from lowermost part of the Tongue River Member, is lower Tiffanian (see Figure 1, notes 4, 5, 6). The holotype may be approximately equivalent in age to the Ollie North local fauna, which has yet to receive study to assign a NALMA. Lithomarker correlation studies by the author place the Ollie North about 20 m below the silcrete-White-Marker-Bed used to demarcate the top of the Ludlow Member (Belt et al., 1984). The duration of the record of *V. codomorphus* on the basis of mammals is estimated at about 2.5 to 3.0 million years (depending on lithostratigraphic interpretation).

## SYSTEMATICS

Class Gastropoda Cuvier, 1797
Subclass Orthogastropoda Ponder and Lindberg, 1996
Superorder Caenogastropoda Cox, 1960
Order Architaenioglossa Haller, 1892 [paraphyletic]
Superfamily Viviparoidea Gray, 1847 *
*Suprafamilial classification after de Bruyne (2003) and Bouchet and Rocroi (2005) after The Taxonomicon compilation (see sources therein).
Family Viviparidae Gray, 1847
Subfamily Lioplacinae Gill, 1863

### *Campeloma* Rafinesque, 1819

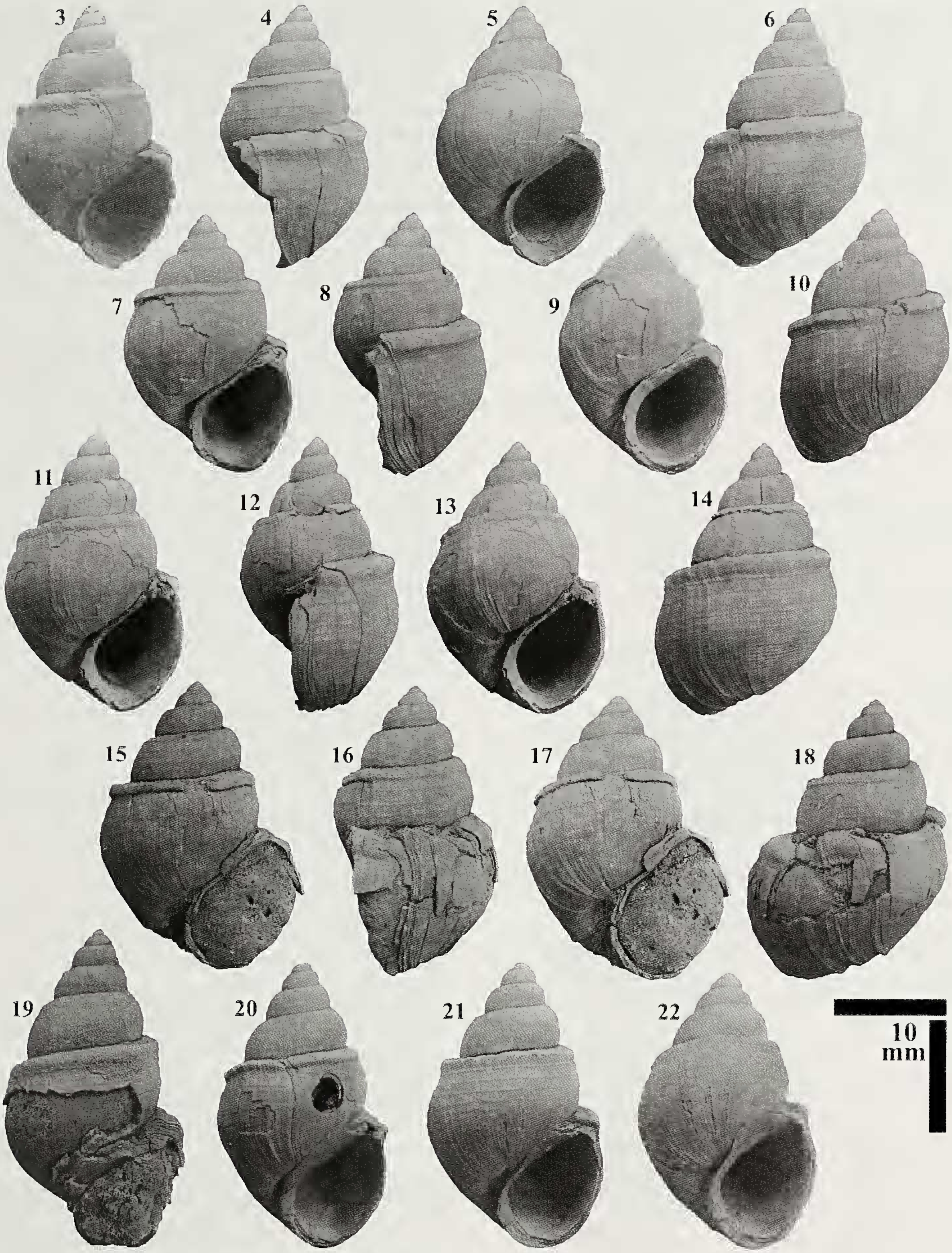
**Etymology:** *campeloma* (Greek), a *bending*, and (Greek) a *margin,* "in exact keeping with the sigmoid character of the aperture of all the species of the genus" (Call, 1883, p. 605).

**Type Species:** *Campeloma crassula* Rafinesque, 1819 (available; see, ICZN, 1999, Opinion 1931).

### *Campeloma acroterion* new species

Figures 3–22

**Diagnosis:** *Campeloma acroterion* is distinguished from other fossil species of *Campeloma* by the regular occurrence of a well-marked revolving shoulder and shelf (Fig. 15) a typical example of shoulder and shelf with defined lip). The shelf is characteristically nearly perpendicular to the axis of coiling (Figure 23), and the shell material forming the shelf and shoulder is very



**Figures 3–22.** *Campeloma acroterion* new species. All specimens were coated with ammonium chloride for photography. **3–6.** USNM-PAL 374598 [UND-JHH S0942], holotype (L1151); 3) apertural. **4.** right lateral. **5.** Basal. **6.** abapertural. **7–10.** USNM-PAL 374600 [UND-JHH S0945], paratype-b (L1151). **7.** Apertural. **8.** right lateral. **9.** Basal. **10.** abapertural. **9–12.** USNM-PAL 374601 [UND-JHH S0946], paratype-c (L1151). **11.** apertural. **12.** right lateral. **13.** Basal. **14.** abapertural. **13–16.** USNM-PAL 374599 [UND-JHH S0943], paratype-a (L1151). **15.** Apertural. **16.** right lateral. **17.** Basal. **18.** abapertural. **19.** UMPC 13602 [UND-JHH S0953], paratype-d (L1151). **19.** apertural. **20.** UMPC 13603 [UND-JHH S0961], paratype-e (L1151). **20.** apertural. **21, 22.** UCMP 37428, paratype-f (L1151). **21.** Apertural. **22.** basal.

much thickened. Shouldering, with tendencies towards shelf development, are common in Paleocene specimens of *C. nebrascense*, exemplified by those specimens assigned to *C. n. whitei*. This subspecies is slightly larger than *C. acroterion* and characteristically has a more sloping shoulder (Figure 23), which is also more variably expressed within a population.

**Description:** Shells medium in size, commonly ranging from 25 to 30 mm in maximum height, a few fragmentary specimens indicate the species might attain heights of up to 35–40 mm (Table 2); maximum number

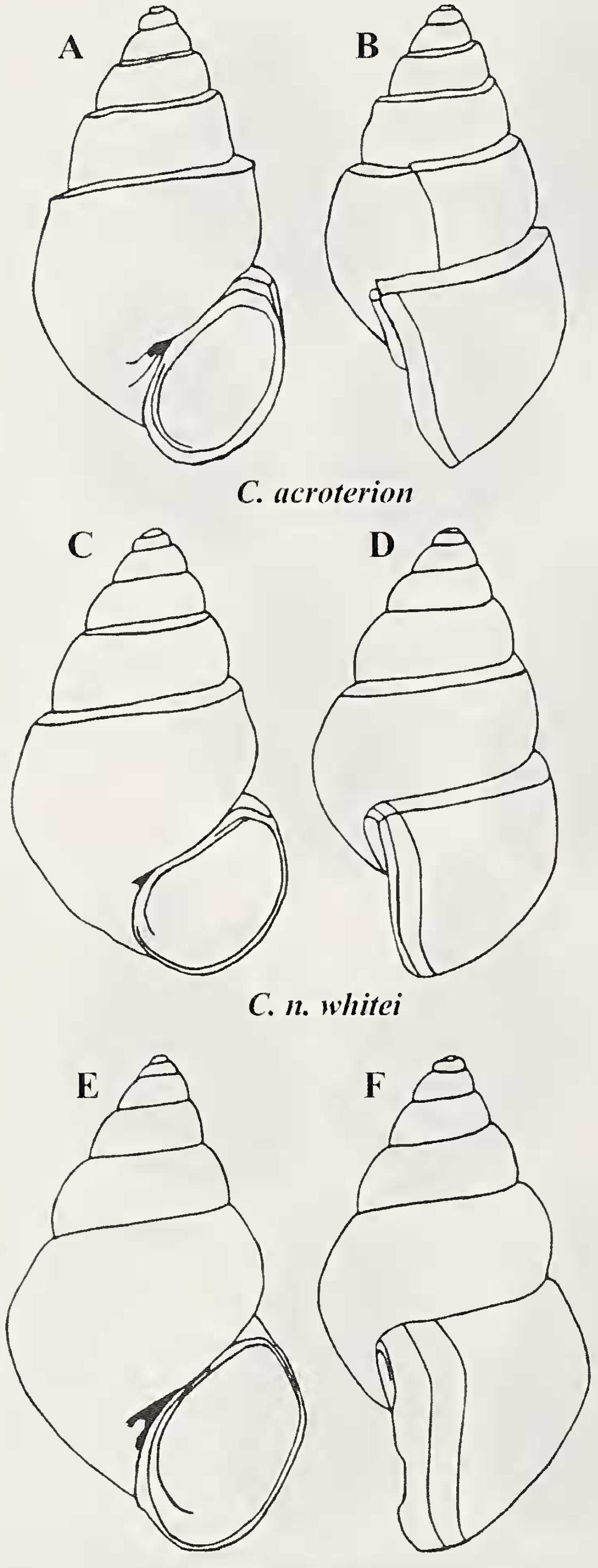
**Table 2.** *Viviparus acroterion*. Measurement Summary (in mm).

| MEASURE | N | MEAN | SD | MIN | MAX |
|---|---|---|---|---|---|
| #W | 14 | 6.6 | 0.3 | 5.7 | 6.9 |
| MSA | 14 | 52 | 3.2 | 46.5 | 56.5 |
| PHI | 7 | 24.6 | 2.8 | 22.6 | 30.6 |
| PWI | 7 | 14.9 | 1.2 | 13.4 | 16.9 |
| PSH1 | 8 | 8.5 | 1.4 | 7.5 | 11.6 |
| PBH | 8 | 16.4 | 1.6 | 15.0 | 19.6 |
| PSW1 (MSW) | 14 | 13.4 | 1.6 | 9.1 | 15.6 |
| PSH2 (MSH) | 14 | 12.7 | 2.0 | 7.8 | 16.1 |
| FAH | 11 | 11.9 | 1.6 | 9.1 | 13.9 |
| FAW | 11 | 8.8 | 1.4 | 6.3 | 10.9 |
| MSW/MSH | 14 | 1.06 | 0.07 | 0.93 | 1.16 |

**Table 3.** Stratigraphic distribution of *Campeloma acroterion* (examined specimens only).

| Stratigraphic Unit<br>State/Province | Localities (Lnos) |
|---|---|
| Ravenscrag Formation | |
| Saskatchewan | L0220, L0436 |
| Ludlow Member, Fort Union Formation | |
| North Dakota | L0184?, L0185? |
| Lebo Member, Fort Union Formation | |
| Montana | L1412(LE?), L1420(LE?) |
| Tullock (Bear) Member, Fort Union Formation | |
| Montana | L0128 |
| Tullock Member, Fort Union Formation | |
| Montana | L0010B, L0027, L0902(TU?), L0924, L0925, L2951 |
| Hell Creek Formation | |
| Montana | L0017A, L0020, L0021, L0053, L0182, L0419?, L0560B, L0586A, L5087?, L1147, L1149?, L1150, L1151[1]*, L1152, L1153, L1356, L1415, L2373, L2949, L3960, L4321 |
| North Dakota | L0155, L0157, L0158, L0159?, L0162, L0163, L0164?, L0167?, L0169?, L0170?, L0175, L0183?, L0923 |
| Lance Formation | |
| Wyoming | L552B, L734, L735?, L738, L744, L880, L3483, L3486?, L4289, L4292, L4296, L4298, L4299 |

Code: ? = Questioned identification based on inadequate preservation. (FM?) = Uncertain formational assignment.
*Type locality.



*C. acroterion*

*C. n. whitei*

*C. n. nebrascense*

**Figure 23.** Outline comparison of *Campeloma* species (each pair representing apertural and right lateral views; not to scale). **23A, B.** *C. acroterion* (L0053, S0217). **23C, D.** *C. nebrascense whitei* (L0349, UMPC 13609). **23E, F.** *C. nebrascense nebrascense* (L0023, UMPC 13604).

of whorls observed 7.4, with many specimens greater than 6.2 whorls; measurements below are for "mature" specimens greater than or equal to 6 whorls; average width-to-maximum height ratio 0.60 (1 SD = 0.03, min. = 0.55, max. = 0.64, n = 7, loc. = 3); shell wall thickness variable, ranging from relatively thin to robust; robustness accentuated by substantial thickening on shoulders; apical tip frequently broken. Shells turbiniform, subovately to elongately conic, with an average mean spire angle for specimens with a complete apex 51.7° (average 6.7 W; 1 SD = 3.7, min. = 43.5°, max. = 58.0°, n = 21, loc. = 2), and for all specimens greater than 6 whorls 48.6° (1 SD = 4.4, min. = 38.0°, max. = 58.0°, n = 64, loc. = 6); spire elevated, with an average mean spire width to mean spire height ratio of 1.04 (average of 6.6 W; 1 SD = 0.07, min. = 0.93, max. = 1.14, n = 12, loc. = 2); average spire height-to-body height ratio 0.51 (1 SD = 0.04, min. = 0.47, max. = 0.59, n = 8, loc. = 3); apical tip rounded, teloconch whorls moderately convex, basal periphery rounded; suture moderately impressed, accentuated by strongly developed shoulder and shelf. Growth lines opisthocyrt, weakly sigmoidal, finely to moderately developed, with minimal coarsening with increasing shell size. Surface sculpture of multiple revolving lirae and some striae, varying from weakly to finely developed, with the greatest density of lines just below (abapical) whorl periphery; striae, as revolving lines of closely spaced punctae and later as grooves, precede revolving lirae on some specimens; shouldering is preceded by one or two revolving lirae; a pair of lirae often define the shoulder, with the area between the lirae becoming much thickened and accentuated, producing a shelf approximately perpendicular to coiling axis; shelf sometimes with a revolving trough, which can be defined by revolving lirae and striae; a revolving shallow sinus can also occur abapical to the shelf; when the shelf is more oblique to the axis of coiling, its appearance is as a well-defined, usually rather angular, lip. Umbilicate; as a narrow, but well defined opening. Aperture ovate, parietal wall relatively thin; average aperture width to height ratio measured in plane of aperture 0.75 (1 SD = 0.02, min. = 0.69, max. = 0.78, n = 9, loc. = 2), measured in plane of coiling axis 0.79 (1 SD = 0.03, min. = 0.72, max. = 0.86, n = 14, loc. = 3), with a foreshortened change in aperture height of about 8%. Individual specimen measurements are given in Appendix 2 (for graphs of parameters, see Hartman, 1984).

**Etymology:** *acroterion* (Greek), a promontory; as in a projection or extremity; here used in reference to the development of a well-defined shelf.

**Type Specimens:** Holotype, USNM-PAL 374598 (UND-JHH S0942); paratype-a, 374599 (UND-JHH 0943); paratype-b, 374600 (UND-JHH S0945); paratype-c, USNM-PAL 374601 (UND-JHH S0946); paratype-d, UMPC 13602 (UND-JHH S0953); paratype-e, UMPC 13603 (UND-JHH S0961); paratype-f, UCMP 37428; all from Locality L1151 (see Type Locality and Appendix 1, Locality Register), Hell Creek Formation, Garfield County, Montana.

**Chresonyms–Nomenclatural Summary:** Specimens assigned to this taxon were most frequently identified either as *Campeloma nebrascense* or *C. n. whitei* (see Previously Illustrated Specimens and Appendix 2 for examples of previous identifications).

**Previously Illustrated Specimens now assigned to *C. acroterion***

Figured specimen, USNM-PAL 9029a (L3340)
  1883b White, pl. 28, fig. 4a (line drawing) [figured as *C. multilineata* and herein identified as *C. acroterion*?].
Figured specimen, USNM-PAL 9029b (L3340)
  1883b White, pl. 28, fig. 4b (line drawing) [figured as *C. multilineata* and herein identified as *C. acroterion*?].
  1883d White, pl. 27, fig. 7 (redrawing of White, 1883b) [reidentified as *C. nebrascense whitei* by Russell (1931a) and affirmed by Tozer (1956)].
Figured specimen, GSC 38365 (L0436)
  1974 Russell, p. 48, 49, figs. 4a, b [figured as *C. n. whitei*]; figured specimen, UMPC 12432 (L0010b).
  1976 Hartman, pl. VII, figs. 10, 11 (unpublished Master's Thesis) [figured as *C. n. whitei*].
Figured specimen, UMPC 12434 (L0027)
  1976 Hartman, pl. VII, fig. 12 (unpublished Master's Thesis) [figured as *C. n. whitei*].
Figured specimen, UMPC 12433 (L0027)
  1976 Hartman, pl. VII, fig. 15 (unpublished Master's Thesis) [figured as *C. n. whitei*].
Figured specimen, UMPC 12435 (L0020)
  1976 Hartman, pl. VII, fig. 13 (unpublished Master's Thesis) [figured as *C. n. whitei*].
Figured specimen, USNM-PAL 374598 (L1151)
  1984 Hartman, pl. 1, figs. 1–4 (unpublished Ph.D. Dissertation) [figured as holotype of *C. acroterion*].
Figured specimen, USNM-PAL 374600 (L1151)
  1984 Hartman, pl. 1, figs. 5–8 (unpublished Ph.D. Dissertation) [figured as paratype-b of *C. acroterion*].
Figured specimen, USNM-PAL 374601 (L1151)
  1984 Hartman, pl. 1, figs. 9–12 (unpublished Ph.D. Dissertation) [figured as paratype-c of *C. acroterion*].
Figured specimen, USNM-PAL 374599 (L1151)
  1984 Hartman, pl. 1, figs. 13–16 (unpublished Ph.D. Dissertation) [figured as paratype-a of *C. acroterion*].
Figured specimen, UMPC 13602 (L1151)
  1984 Hartman, pl. 1, figs. 17 (unpublished Ph.D. Dissertation) [figured as paratype-d of *C. acroterion*].

Figured specimen, UMPC 13603 (L1151)
1984 Hartman, pl. 1, figs. 18 (unpublished Ph.D. Dissertation) [figured as paratype-e of *C. acroterion*].
Figured specimen, UCMP 37428 (L1151)
1984 Hartman, pl. 1, figs. 19, 20 (unpublished Ph.D. Dissertation) [figured as paratype-f of *C. acroterion*].

**Type Locality (L1151):** The type locality was discovered by Harley Garbani (Los Angeles County Museum) as part of the search for dinosaurs and mammals in Hell Creek country. J.H. Garbani and N.T. Greenwald collected a specimen of the type series of *Campeloma acroterion* from "Harley's shell bed" on July 7, 1976 (paratype-f, UCMP 37428; field number – JDA-76-7/7-4; UCB locality number – D-7274). The author was given directions to the locality by Garbani and studied and collected the holotype, paratypes, and measured specimens on: 1979 (July 26–27, UM; paratype-a, b, c, d, e); 1982 (July 26, Hartman, UM; holotype); 1991 (July 20; Hartman, W.D. Peck, and D.E. Heinen, UND); 2002 (July 18; Hartman; R. Mattison, Wellesley College; S. Uthus, UND); and 2008 (July 22; A.E. Bogan, D.P. McCollor, UND-EERC; K. Voegele, Concordia College; and others).

Locality L1151 occurs in the East Ried Coulee unit (see Hartman et al., 2014) of the Hell Creek Formation at approximately 27.4 m (90 ft) (Hartman, 1998) below the Z coalbed (after Archibald, 1982) that approximates the top of the formation with the overlying Tullock Member of the Fort Union Formation (Hartman et al., 2014). The locality is at an elevation of about 823 m (2700 ft) on a north-trending promontory, near the center of the south edge of the NW¼ SW¼ NE¼ sec. 5, T. 20 N., R. 37 E., Trumbo Ranch Quadrangle (1971), Garfield County, Montana (see map, Figure 24).

**General Distribution:** Recognizably distinctive specimens of *Campeloma acroterion* are found throughout the Lance and Hell Creek Formations in the northern Great Plains (Figure 24). Specimens are frequently a quantitatively important element of the faunule and are often the dominant gastropod. Similar specimens, with distinctively shelved and shouldered whorls, also occur in the overlying Fort Union (Tullock, Bear, and lower Ludlow Members [Tullock Formation after others and Frye, 1967]) and basal Ravenscrag Formations. The poorly preserved specimens previously reported from the upper part of the Livingston Group of the Crazy Mountains Basin of south-central Montana are now reassigned to horizons within the Hell Creek and Fort Union Formations (Table 3; revised from Hartman, 1984, table 24).

Uppermost Cretaceous records from the Hell Creek Formation in Custer, Dawson (or Wilbaux), Garfield, Golden Valley, Meagher, McCone, Rosebud, Wibaux (or Dawson), and Yellowstone Counties, Montana; from Bowman, Emmons, Grant, Morton, Sioux, and Slope Counties, North Dakota; from the Lance Formation in Niobrara County, Wyoming; from the Paleocene Fort Union Formation members including the Bear Member in Wheatland County, Montana; from the Tullock Member in Daniels, Garfield, and McCone Counties, Montana; with uncertainty from the Lebo Member in Wheatland County; from the Ludlow Member in Slope County, North Dakota; and from the Ravenscrag Formation in Cypress Hills in southernmost Saskatchewan. Cadastral location data for examined *C. acroterion* are given in Hartman (1984, table 25).

Frye (1967, 1969) lithostratigraphically organized the Hell Creek Formation into several members. Identification of Frye's (1967) specimens shows *C. acroterion* to occur in the Pretty Butte (L0183?), Huff (L0170?, L0175), and Fort Rice (L0155, L0157, L0158, L0159?, L0162, L0163, L0164?, L0167?, L0169?) members. Carlson (1979; personal communication, 15 June 1981), Murphy et al. (2002), and others questioned the utility and ability of others to recognize these subdivisions. Butler (1980), Butler and Hartman (1999), Lund et al. (2002) and Hartman et al. (2014) suggested that a Hell Creek Formation architecture exists and could be correlated in both surface exposures and subsurface logs. The member contacts proposed by Frye (1967, 1969) may not be as useful as he hoped, but his lithofacies have been recognized significantly beyond the limits of their type sections (Butler, 1980; Hartman et al., 2014).

Subfamily Viviparinae Gray, 1847

### *Viviparus* Montfort, 1810

**Etymology:** *viviparus*, that brings forth its young alive.

**Type Species:** *Viviparus fluviorum* Montfort, 1810 (= *Helix vivipara* Linnaeus, 1758) (available, see ICZN, 1959, Opinion 573).

### *Viviparus purgatorius* new species
Figures 25–66

**Diagnosis:** *Viviparus purgatorius* is distinguished from other fossil Viviparinae on the basis of a suite of characters including a much greater mean spire angle, much more inclined growth lines, strongly keeled and crenulated periphery (in adult specimens), and development of nodes in adult forms. Only *V. retusus* growth lines are as acutely inclined to the periphery, but it differs from *V. purgatorius* in being much smaller in size for the same number of whorls, in possessing a depressed spire, and in lacking significant sculpture (compare selected *Viviparus* morphologies, see Figure 67).

*Viviparus formosus* resembles *V. purgatorius* in maintaining a large mean spire angle for a large shell size, but it differs from *V. purgatorius* in possessing less inclined growth lines, and a more elevated spire, in lacking nodes, and in lacking a crenulated, strongly angular basal periphery. *Viviparus* sp. form-W also resembles *V. purgatorius* in maintaining a large mean spire angle

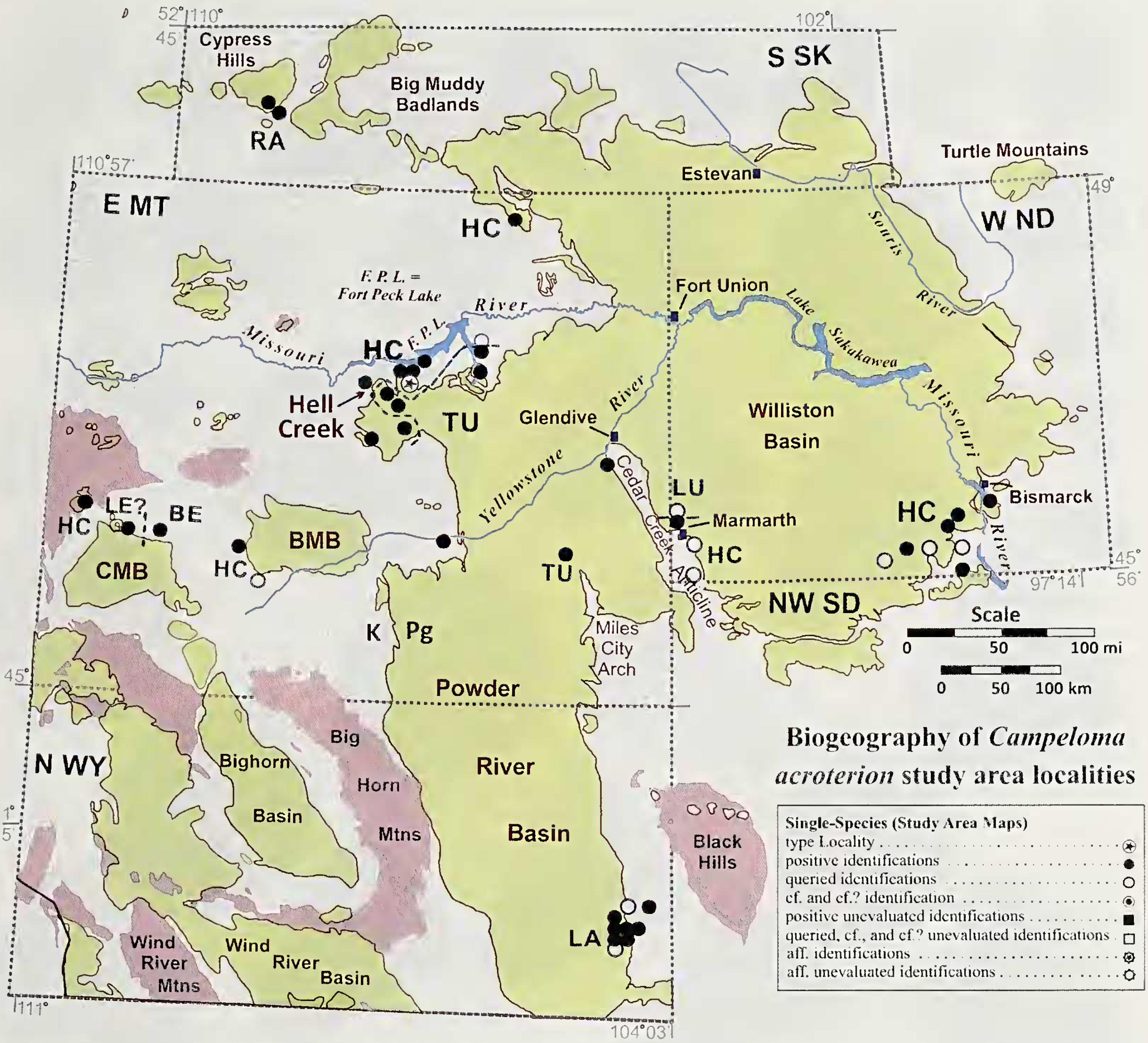


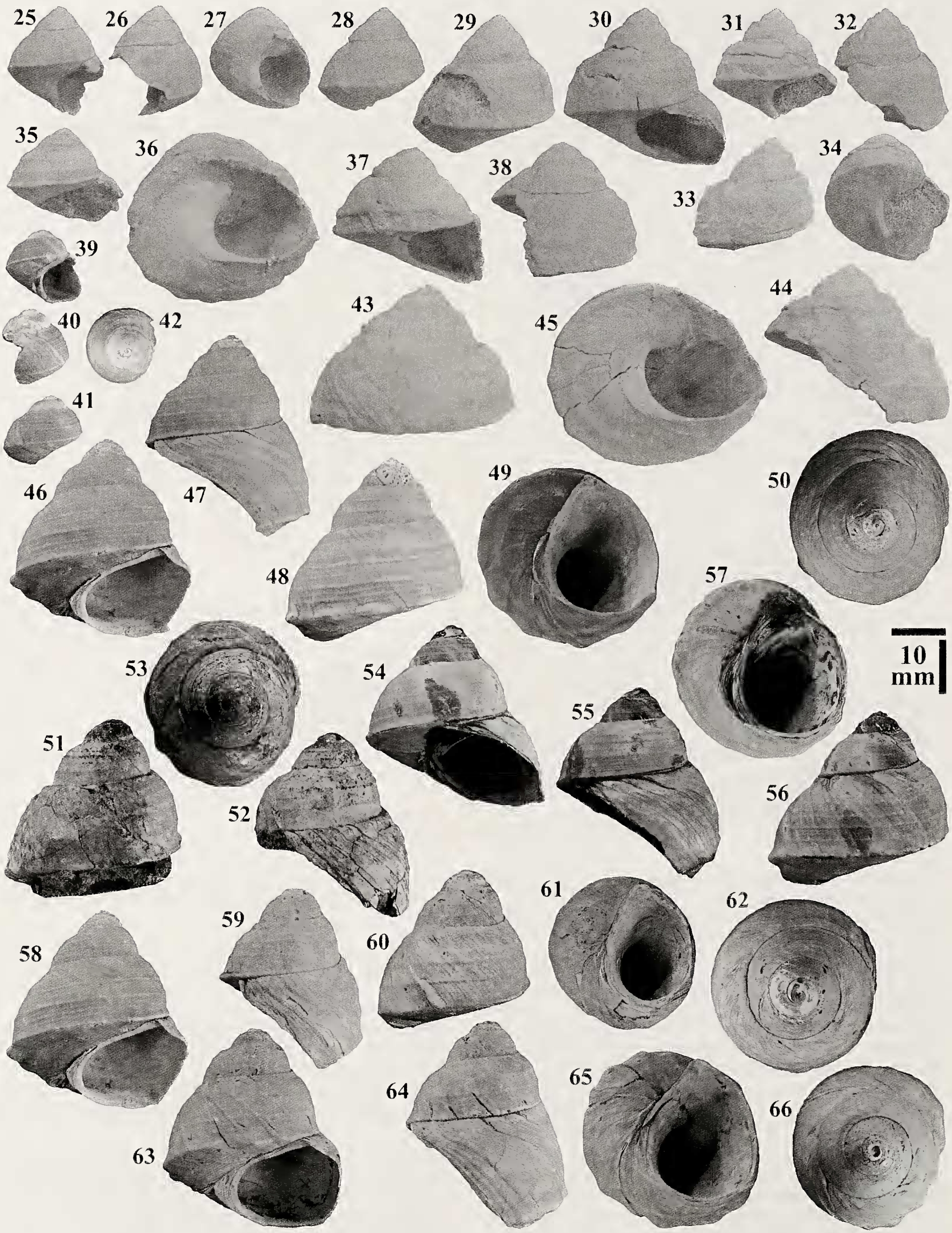
**Figure 24.** Biogeography of *Campeloma acroterion* localities in the northern Great Plains and intermontane basins of the USA and Canada. Upland areas (roughly Laramide uplifts) are shown in pink, with preserved Paleogene and younger sediments preserved in basins shown in yellow (see Abbreviations.)

for a large shell size, but differs from *V. purgatorius* most obviously in possessing a much more rounded basal periphery, but also in lacking nodes, a crenulated periphery, and in possessing a larger last whorl expansion ratio.

Other noduliferous species proximal to *V. purgatorius* are Paleocene *Viviparus codomorphus* and Cretaceous *V. thompsoni*. *Viviparus codomorphus* differs from *V. purgatorius* in possessing a more blunted apex, in the infrequency of adapical node development (only one specimen has nodes developed), and in lacking a crenulated periphery. *V. thompsoni* differs from *V. purgatorius* in possessing a distinctive pattern of nodes and node ridges. *Viviparus purgatorius* also differs from *V. thompsoni* in lacking any significant basal surface sculpture (other than spiral lirae) on the latter whorls of larger specimens.

**Description:** When this species was originally recognized and described informally, no undeformed large specimens of this taxon existed, prohibiting a rigorous, numerically calibrated description. Essentially complete, undistorted large specimens were subsequently discovered by D.L. Lofgren (see Appendix 2).

Shells relatively large in size, attaining a maximum height of about 35 mm; maximum number of whorls observed 6.9; measurements given below are for mature specimens from 5 to 6 greater whorls; shell walls relatively thin (Table 4). Shells subtrochiform, globosely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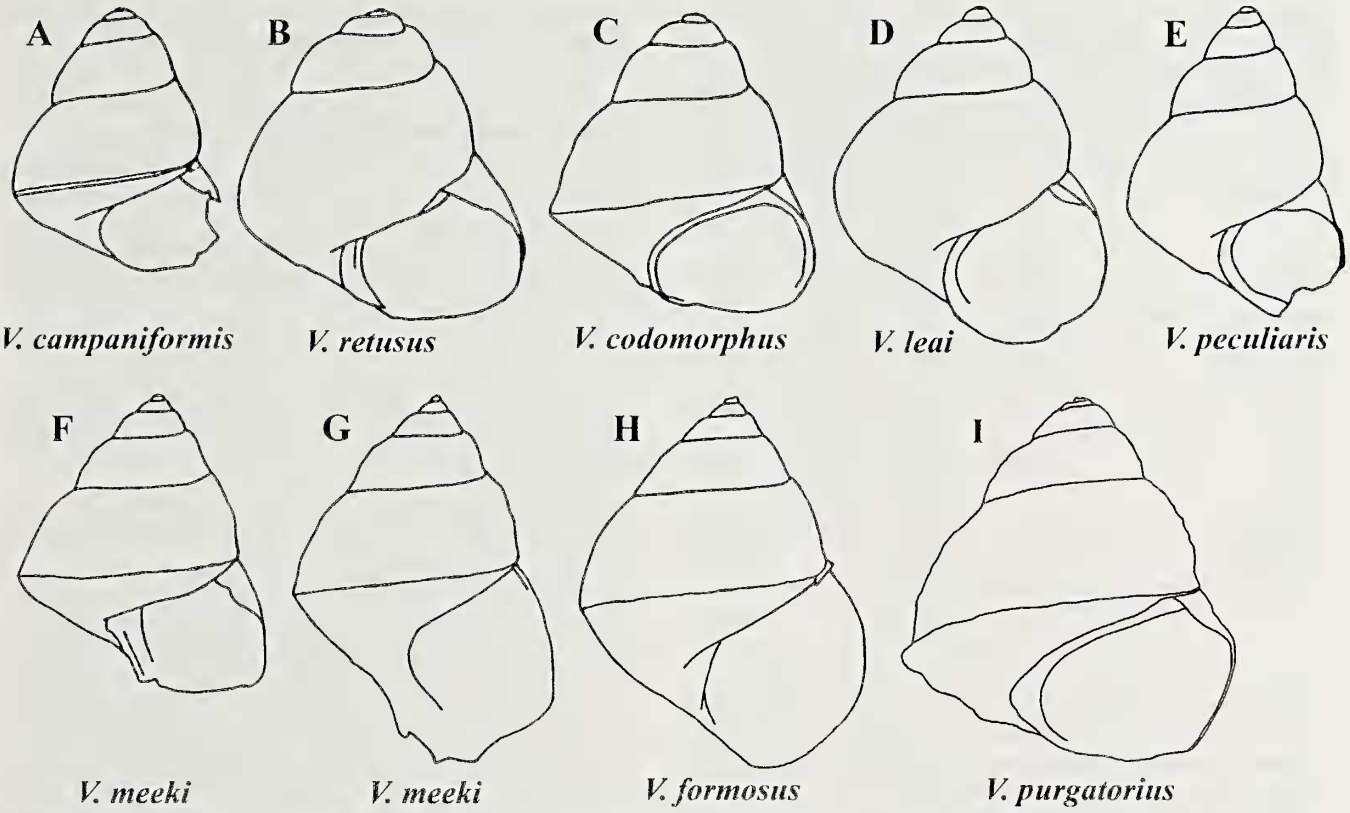


**Figure 67.** Outline comparison of *Viviparus* species (apertural views, not to scale). **67A–C.** Blunted apex. **67A.** *V. campaniformis* (L0070; S0517). **67B.** *V. retusus* (L0435; USNM-PAL 2155). **67C.** *V. codomorphus* (L0049; USNM-PAL 374604). **67D.** Pointed apex, rounded whorls and periphery. **67D.** *V. leai* (L2305; USNM-PAL 2154). **67E–I.** Pointed apex, subtrochiform marginal outline. **67E.** *V. peculiaris* (L0349; S0309). **67F.** *V. meeki* (L0953; USNM-PAL 374985). **67G.** *V. meeki*, narrower form (L0953; USNM-PAL 374986). **67H.** *V. formosus* (L0435; USNM-PAL 2159). **67I.** *V. purgatorius* (L6460, S10441).

conic, with an average mean spire angle of 68.5° (#W $\geq$ 5.5: aver #W = 5.7 W, 1 SD = 9.26, min = 61.9°, max = 75.0°, n =2, loc = 2; #W $\geq$ 5.0: MSA = 66.6°, 1 SD = 5.1, min. = 61.9°, max. = 73.5°, n = 4, loc. = 3; #W $\geq$ 4.6: MSA = 68.8°, 1 SD = 6.5, min. = 81.5°, max. = 60.0°, n = 16, loc. = 6); average last whorl expansion ratio of 1.88 (1 SD = 0.03, min. = 1.84, max. = 1.90, n = 4, loc. = 2); apical tip bluntly pointed, apical whorls not substantially produced; teloconch whorls broadly convex, with an average mean spire width to mean spire height ratio of 3.3 (aver of 5.5 W: 1 SD = 1.00, min. = 1.52, max. = 1.51, n = 6, loc. = 1); spire height-to-body height ratio 0.30 (1 SD = 0.04, min. = 0.22, max. = 0.30, n = 3, loc. = 1); slight adapical shouldering proximal to the suture; upper spire and basal periphery carinate–angular, with basal periphery often strongly angular; suture slightly to very slightly impressed. Growth lines prosocline, very strongly inclined at about 38°( #W $\geq$ 5.0:

**Figures 25–66.** *Viviparus purgatorius* new species. Specimens from Localities L0010b and L0214 were coated with ammonium chloride for photography. **25–28.** GSC-IP 76957, hypotype (L0214). **25.** apertural. **26.** right lateral. **27.** basal. **28.** apertural. **29.** GSC-IP 76958, hypotype (L0214). **29.** abapertural (specimen slightly distorted). **30.** UMPC 12427 [UND-JHH S0754], paratype-a (L0010b). **30.** apertural (specimen distorted). **31–34.** USNM-PAL 374614 [UND-JHH S0755], paratype-b (L0010b). **31.** apertural. **32.** right lateral. **33.** abapertural. **34.** basal (specimen slightly distorted, adaperturally depressed). **35.** UMPC 13616 [UND-JHH S0757], paratype-d (L0010b). **35.** apertural. **36.** UMPC 13617 [UND-JHH S1025], paratype-e (L0010b). **36.** basal (specimen distorted). **37, 38.** UMPC 12428 [UND-JHH S0756], paratype-c (L0010b). **37.** apertural. **38.** right lateral. **39–41.** USNM-PAL 374613 [UMPC 12429; UND-JHH S0753], paratype-f (was unpublished holotype) (L0010b). **39.** right lateral. **40.** abapertural. **41.** basal (specimen axially compressed). **42–45.** UND-JHH S10443, figured young specimen, topotype (L6460). **42.** apertural. **43.** right lateral. **44.** abapertural. **45.** apical. **46–50.** USNM-PAL request1 [UND-JHH S10441], holotype (L6460). **46.** apertural. **47.** right lateral. **48.** Abapertural. **49.** apertural flush. **50.** apical. **51–53.** USNM-PAL will request2 [UND-JHH S10445], paratype-g, topotype (L6460). **51.** apertural. **52.** right lateral. **53.** apical. **54–57.** USNM-PAL request [UND-JHH S10439], paratype-h, (L6460). **54.** apertural oblique. **55.** right lateral. **56.** Abapertural. **57.** apertural flush. **58–62.** UND-PC 16163 [UND-JHH S10446], paratype-I (L6460). **58.** apertural. **59.** right lateral. **60.** abapertural. **61.** apertural flush. **62.** apical. **63–66.** UND-PC 16164 [UND-JHH S10447], paratype-j (L6460). **63.** apertural. **64.** right lateral. **65.** apertural flush. **66.** apical.

**Table 4.** *Viviparus purgatorius.* Measurement Summary (in mm).[1]*

| MEASURE | N | MEAN | SD | MIN | MAX |
|---|---|---|---|---|---|
| #W | 8 | 5.7 | 0.6 | 5.0 | 6.9 |
| MSA | 6 | 68.2 | 5.2 | 61.9 | 75.0 |
| MHI | 5 | 35.4 | 2.2 | 33.1 | 38.3 |
| PHI | 7 | 31.5 | 6.7 | 18.8 | 37.1 |
| PWI | 10 | 27.8 | 5.4 | 17.3 | 33.0 |
| PSH1 | 5 | 8.3 | 2.4 | 5.9 | 11.4 |
| PBH | 5 | 25.3 | 1.9 | 23.3 | 28.0 |
| PSW1(MSW) | 5 | 25.5 | 5.3 | 17.4 | 32.4 |
| PSW2 | 5 | 13.7 | 3.2 | 9.3 | 18.3 |
| PSH2(MSH) | 4 | 18.0 | 6.5 | 6.5 | 26.3 |
| PAH | 3 | 14.2 | 0.6 | 13.6 | 14.8 |
| PAW | 3 | 26.5 | 12.4 | 17.8 | 40.7 |
| FAH | 2 | 24.6 | 3.2 | 22.3 | 26.9 |
| FAW | 2 | 19.9 | 2.8 | 17.4 | 21.3 |
| GLA | 4 | 43.0 | 10.0 | 31.0 | 53.0 |
| MSW/MSH | 6 | 3.3 | 1.00 | 1.5 | 4.5 |
| MSW/PSW2 | 15 | 1.9 | 0.10 | 1.7 | 2.1 |

*On specimens with ≥ 5 #W.

GLA = 41.2°, 1 SD = 10.1, min. = 31.0°, max. = 53.0°, n = 5, loc. = 2; nearly straight, but apparently with a slight adapertural arch proximal to suture; fine-to-moderate development, becoming coarser on latter whorls of larger specimens. Sculpture consists, in part, of a pair of slightly raised revolving ridges of approximately equal prominence and nearly equally spaced between ad- and abapical sutures, strongly reminiscent of some specimens of *V. meeki*; revolving ridges appear to be most clearly seen on upper spire whorls, becoming more obscure with increasing shell height; other revolving lirae may be approximately equal in prominence to the pair of raised ridges, and may thus obscure the basic sculptural similarity with *V. meeki*; Paleogene revolving sculpture is obscure to absent, but some lirae occur below (abapical) basal periphery, are of approximately equal prominence, and are best seen on smaller specimens; a few specimens show a slight, basal surface ridge without nodes; basal periphery keeled and slightly to moderately crenulated on larger specimens, reminiscent of *V. thompsoni*; crenulation may be enhanced by lateral distortion, but its existence, although seeming to be somewhat variable, appears definitely to be a feature of this species. Without umbilicus, with thick inner apertural wall and umbilical area covered by a distinct, relatively wide and thickened columellar callus. Aperture poorly known, ovate, tapers adapically, with a rather strong outer lip angulation at the whorl periphery; parietal lip thins along basal whorl; aperture plane strongly inclined; average aperture width-to-height ratio measured in plane of aperture 0.78 (1 SD = 0.09, min. = 0.9, max. = 2.9, n = 4, loc. = 1), measured in plane of coiling axis 1.62 (1 SD = 0.85, min. = 0.91, max. = 2.86, n = 4, loc. = 1), with a foreshortened change in aperture height of about 48%. Individual specimen measurements are given in Appendix 2 (for graph of parameters, see Hartman, 1984).

**Etymology:** *purgatorius*, named after Purgatory Hill (L0010), McCone County, Montana, the discovery location for the species.

### Chresonyms–Nomenclatural Summary

1974 *Viviparus formosus* (Meek and Hayden): Russell, p. 46, 47, figs. 3e, f.

1976 *Viviparus* aff. *V. thompsoni* White: Hartman, p. 116–119, 176, pl. VII, figs. 1–5 (unpublished M.S. Thesis).

1984 *Viviparus purgatorius* Hartman, p. 445–454, pl. 8, figs. 1-24 (unpublished Ph.D. Dissertation).

### Previously Illustrated Specimens now assigned to *V. purgatorius*

Figured specimen, GSC 38361 (L0224)
- 1974 Russell, p. 46, 47, figs. 3e, f (figured as *V. formosus*).

Figured specimen, GSC 76957 (L0214)
- 1984 Hartman, pl. 8, figs. 1–4 (unpublished Ph.D. Dissertation) [figured as *V. purgatorius*].

Figured specimen, GSC 76958 (L0214)
- 1984 Hartman, pl. 8, figs. 5, 6 (unpublished Ph.D. Dissertation) [figured as *V. purgatorius*].

Figured specimen, UMPC 12427 (L0010b)
- 1976 Hartman, pl. VII, figs. 1, 2 (unpublished Master's Thesis) [figured as *V.* aff. *V. thompsoni*]
- 1984 Hartman, pl. 8, figs. 7, 8 (unpublished Ph.D. Dissertation) [figured as paratype-a of *V. purgatorius*].

Figured specimen, UMPC 12428 (L0010b)
- 1976 Hartman, pl. VII, figs. 4, 5 (unpublished Master's Thesis) [figured as *V.* aff. *V. thompsoni*]
- 1984 Hartman, pl. 8, figs. 17–20 (unpublished Ph.D. Dissertation) [figured as paratype-e of *V. purgatorius*].

Figured specimen, UMPC 12429 (L0010b)
- 1976 Hartman, pl. VII, fig. 3 (unpublished Master's Thesis) [figured as *V.* aff. *V. thompsoni*]
- 1984 Hartman, pl. 8, figs. 21–24 (unpublished Ph.D. Dissertation) [figured as holotype of *V. purgatorius*].

Figured specimen, UMPC 13617 (L0010b)
- 1984 Hartman, pl. 8, figs. 9, 10 (unpublished Ph.D. Dissertation) [figured as paratype-e of *V. purgatorius*].

Figured specimen, UMPC 13616 (L0010b)
- 1984 Hartman, pl. 8, figs. 11, 12 (unpublished Ph.D. Dissertation) [figured as paratype-d of *V. purgatorius*].

Figured specimen, USNM-PAL 374614 (L0010b)
- 1984 Hartman, pl. 8, figs. 17, 20 (unpublished Ph.D. Dissertation) [figured as paratype-b of *V. purgatorius*].

**Type Specimens:** Holotype, USNM-PAL 611016 (UND-JHH S10441, L6460); paratype-a UMPC 12427 (UND-JHH S0754, L0010b); paratype-b, USNM-PAL

374614 (UND-JHH S0755, L0010b); paratype-c, UMPC 12428 (UND-JHH S0756, L0010b); paratype-d, UMPC 13616 (UND-JHH S0757, L0010b); paratype-e, UMPC 13617 (UND-JHH S1025, L0010b); paratype-f, USNM-PAL 374613 (UMPC 12429, UND-JHH S0753, L0010b); paratype-g, USNM-PAL 611017 (UND-JHH S10445, L6460); paratype-h, USNM-PAL 611018 (UND-JHH S10439, L6460); paratype-I, UND-PC 16163 (UND-JHH S10446, L6460); and paratype-j, UND-PC 16164 (UND-JHH S10447, L6460) from the Tullock Member, Fort Union Formation, McCone County, Montana (see Type Locality and Appendix 1, Locality Register).

**Reference Specimens:** Hypotypes, GSC-IP 76957, 76958, Locality L0214; Ravenscrag Formation, Big Muddy Valley, on Minton map (1974), Saskatchewan.

**Type Locality (L6460):** The type locality of *Viviparus purgatorius* was discovered August 12, 1994 by Donald L. Lofgren (Raymond M. Alf Museum) and the holotype and paratypes-h and -j were collected from the Racetrack Ridge locality on August 12, 1994, by D.L. Lofgren and W.A. Clemens (University of California-Berkeley) (field 94DLL8-12-2, Alf I94161), along with other measured specimens (see Appendix 2). The specimens were subsequently donated to the UND-PC collections. Paratype-i was collected by Hartman on September 16, 1995 (L6460b; [a–e sites were recognized). Paratype-g was collected on July 27, 2000 by J.H. Hartman, D. Lamb, D.L. Lofgren, A.C. Raser, G.C. Winsinger. These and other specimens were collected from the Tullock Member of the Fort Union Formation about 36.6 m above base of the MCZ coalbed of Lofgren (1995, McGuire Creek Z) representing here the base of the formation, marking the contact with the underlying Hell Creek Formation. The locality is at an elevation of about 742.8 m (2437 ft) in the W½ NW¼ NE¼ sec. 16, T. 21 N., R. 43 E., on the Nelson Creek Bay Quad. (1973) in McCone County, Montana (see map, Figure 68).

**Reference Locality (L0010b):** Discovery location paratypes (a–f) of *Viviparus purgatorius* were collected by R.E. Sloan and J.H. Hartman in 1974 from Purgatory Hill at an elevation of about 751.3 m (2478 ft), located in SE¼ NE¼ SE¼ NW¼ SW¼, sec. 36, T. 23 N., R. 43 E., Bug Creek Quad. (1973), McCone County, Montana. Locality L0010b is located on the north-facing exposures near the top of the butte in a north-south trending channel capped by a sandstone monolith. The channel cut is stratigraphically about 30.5 m above the MCZ coalbed representing the base of the Tullock Member, Fort Union Formation (see also Bell, 1965, measured section E). Locality L0010b is also the a source of late Puercan mammals interpreted to be Pu2–3 NALMA reported by Van Valen and Sloan (1965) and frequently thereafter (see Hartman, 1978; Archibald, 1987; Lofgren, 1995) (see Figure 68).

**Literature Distribution:** *Viviparus purgatorius* was reported by Hartman (1976) as *V.* aff. *V. thompsoni* (see Chresonyms) from the Tullock Formation in McCone County (L0010b), Montana. The only other previous report of specimens assignable to this taxon were made by L.S. Russell (*in* Fraser and others, 1935; Russell, 1974) from the Ravenscrag Formation in southernmost Saskatchewan. Russell's identifications, now assigned to *V. purgatorius*, included *V. formosus*, *V. leidyi*, and *V. meeki* (= *V. trochiformis*).

**General Distribution:** *Viviparus purgatorius* was known primarily from distorted and/or incomplete specimens throughout its range in northeastern Montana in the Tullock Member in McCone (L0010b, L0027?) and Garfield (L2951) Counties; southern Saskatchewan in the Ravenscrag Formation (L0209?, L0212?, L0214, L0217?, L0219, L0220, L0223?, L0224, L0225, L0229?, and L0436); and from a queried occurrence in south-central Montana in the Bear Member (Fort Union Formation) in Wheatland County (L0128; see Hartman and Krause, 1993); and from a queried occurrence in the Tongue River Member of the Fort Union Formation in Musselshell County (L1458?) (Figure 68; Table 5) (see Hartman, 1984, table 60 for a cadastral record of occurrences). The record from the Tongue River Member may be referable to *V. meeki*, which, if true, would restrict the age of *V. purgatorius* to early Paleocene (~Pu2–3; L0010b) in Montana. The occurrences of *V. purgatorius* in the Ravenscrag Formation stratigraphically range from a documented early Paleocene locality (Pu2; L0220) in the lower part of the Ravenscrag Formation in the area of Anxiety Butte, to an unresolved Paleocene age in the upper middle part of the formation just above the Willowbunch coal in the Big Muddy Valley area. On the basis of palynological data, Sweet (1978) stated that the strata of the Willowbunch coal zone may be correlative with the Estevan or Boundary coal sequence in the Estevan area, which would probably make the occurrence of *V. purgatorius* in the Big Muddy Valley at least mid Paleocene (Ti2) (see Whitaker and others, 1978, pl. 2, Regional Correlation Sections A–A′).

**Discussion – *Viviparus purgatorius*:** Although recognizably distinct, this species was first found plastically deformed. The style of deformation and preservation of Tullock Member and Ravenscrag Formation specimens was very similar suggesting similar shell structure. *V. purgatorius* could be identified on the basis of the features mentioned in the Diagnosis and Description, but the deformed specimen variable whorl convexity, growth line angle, and mean spire angle could make positive identification difficult. The discovery of numerous undistorted specimens at Locality L6460 at Racetrack Ridge confirmed the interpretation of the proposed species (Hartman, 1984) and provided measurements not previously available (Appendix 2).

Probably all of the Ravenscrag Formation specimens identified by Russell (in Fraser and others, 1935; Russell, 1974) as *V. formosus* and *V. leidyi*, and many

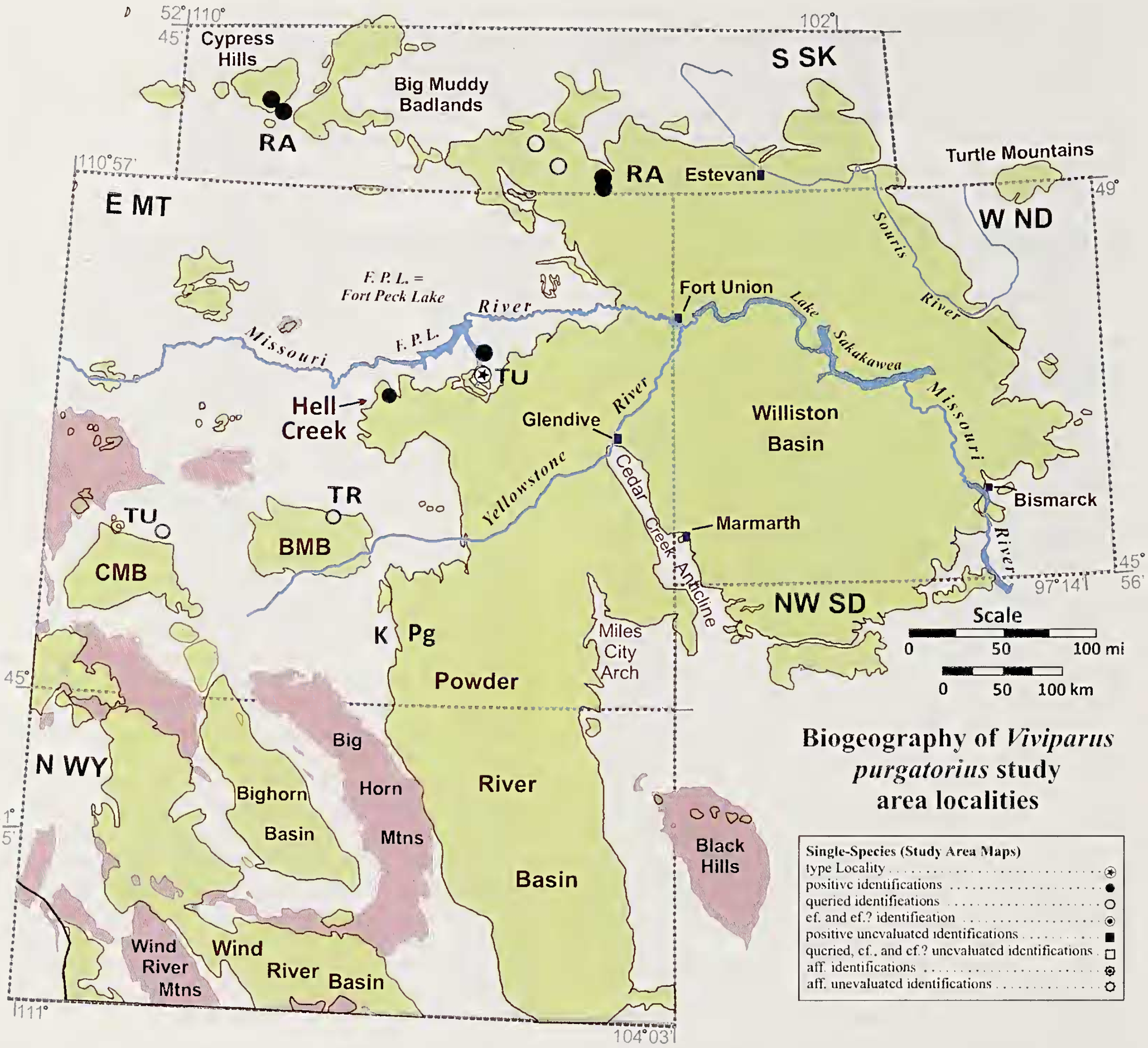


**Figure 68.** Biogeography of *Viviparus purgatorius* localities in the northern Great Plains and intermontane basins of the USA and Canada (see Figure 24 for map notes).

**Table 5.** Stratigraphic distribution of *Viviparus codomorphus* (examined specimens only).

| Stratigraphic Unit State | Localities (Lnos) |
|---|---|
| Fort Union Formation undivided | |
| Montana | L0936 |
| Ludlow (Upper) (Slope) Member, Fort Union Formation | |
| North Dakota | L4232A, L4232B |
| Ludlow Member, Fort Union Formation | |
| Montana | L0049[1]*, L0939 |

*Type locality; Area interpreted by Vuke et al. (2003) to be Tongue River Member (see text).

identified as *V. meeki* (= *V. trochiformis*), are referable to *V. purgatorius*. The specimens assigned to these younger Paleocene taxa are all very similar and are at once distinguished from *V. purgatorius* by possessing an umbilicus. They also differ in possessing a more pointed apex, less inclined growth lines, and a less angular periphery.

Small and incomplete specimens of *V. purgatorius* could be difficult to separate from either *V. campaniformis* or *V. retusus*, as all three species have a blunt apex and a more or less carinate periphery. Small specimens of these species should not be positively identified unless larger specimens are present in the population. The adult morphologies are, however, quite dissimilar.

**Discussion – *Viviparus* cf. *V. purgatorius*:** All of the specimens assigned to *V.* cf. *V. purgatorius* are from the Ravenscrag Formation (Localities L0214 and L0218) and appear to represent a morphology distinct from *V. purgatorius*. *Viviparus* cf. *V. purgatorius* differs from *V. purgatorius* in being notably more striate, particularly on the last whorl of larger specimens, in possessing a less angular periphery with increasing shell size, and in having a more impressed suture. They are similar in possessing multispiral lirae on upper spire whorls, in lacking an umbilicus, and in possessing strongly inclined growth lines. All of the larger specimens assigned to *V.* cf. *V. purgatorius* are lacking apical whorls. *V. leai* is the only other Paleocene viviparid characterized by revolving striae or punctae, but unlike *V. purgatorius*, it is umbilicate.

***Viviparus codomorphus* new species**
Figures 69–92

**Diagnosis:** *Viviparus codomorphus* is distinguished from other fossil Viviparinae on the basis of a suite of characters including its blunted apical tip (Figure 69), absence of an umbilicus, and mean spire angle for a given number of whorls. *Viviparus codomorphus* is also represented by an atypical specimen (Figure 91, UMPC 13611) displaying adapical nodes and a basal surface ridge. Species with similar morphology are *V. campaniformis* and *V. meeki* (see outline comparisons, Figure 67).

*Viviparus campaniformis* differs from *V. codomorphus* in its greater rounding of apical whorls, more flanged and carinate appearance on upper spire whorls, smaller mean spire angle and last whorl expansion ratio in larger specimens, in attaining a greater shell height for the same number of whorls, and somewhat more inclined growth lines. *V. meeki* differs from *V. codomorphus* in having a pointed apex, attaining an equivalent or somewhat smaller size for a greater number of whorls, and in possessing an umbilicus.

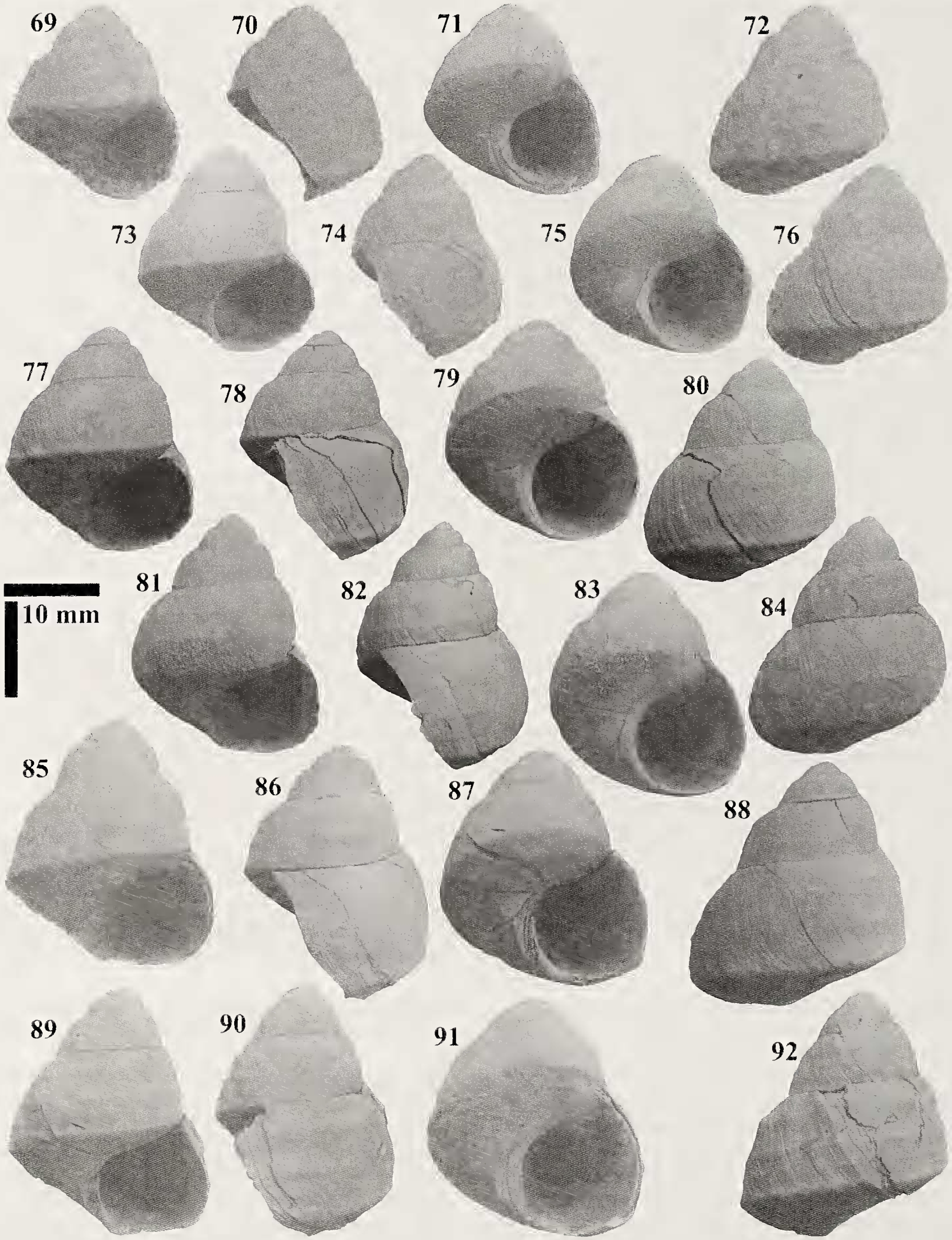
**Description:** Shell medium in size, commonly ranges from 23 to 28 mm in maximum height, rarely exceeding 30 mm; maximum number of whorls observed 5.8, with most specimens ranging from 5.0 to 5.5; measurements given below are for "mature" specimens greater than or equal to 5.0 whorls; average width-to-maximum height ratio 0.82 (1 SD = 0.04, min. = 0.72, max. = 0.90, n = 28, loc. = 4); shell walls moderately thick, frequently robust (Table 6). Shells subtrochiform, broadly conic, with an average mean spire angle for specimens with a complete apex of 62.0° (average of 5.4 W; 1 SD = 3.0, min. = 56.5°, max. = 71.0°, n = 26, loc. = 5), and for all specimens greater than 5.0 whorls of 60.5° (1 SD = 3.3, min. = 53.5°, max. = 71.0°, n = 46, loc. = 5); spire somewhat elevated, with an average mean spire width to mean spire height ratio of 1.34 (average of 5.4 W; 1 SD = 0.08, min. = 1.25, max. = 1.54, n = 22, loc. = 5); last whorl expansion ratio of 1.65 (1 SD = 0.06, min. = 1.54, max. = 1.80, n = 46, loc. = 5); spire height-to-body height ratio 0.38 (1 SD = 0.06, min. = 0.28, max. = 0.48, n = 30, loc. = 5); apical tip slightly blunted, rounded at extreme tip, teloconch whorls broadly convex, with a slight but consistent oblique shoulder proximal to suture; upper spire whorl periphery angular and carinate, becoming more subangular with increasing shell size, but usually maintaining evidence of a peripheral keel; suture slightly to moderately impressed. Growth lines prosocline, with an average growth-line angle of about 23° (approximately determined: mean = 22.7°, 1 SD = 4.2, min. = 15.0°, max. = 31.0°, n = 25, loc. = 5); nearly straight across midwhorl, although frequently with a slight adapertural arch and usually curved over slight shoulder proximal to suture; finely to moderately developed, becoming somewhat more coarse with increasing shell size. Sculpture consists of a pair or more of slightly raised ridges and very obscure to absent secondary revolving lirae and striae; peripheral carina on upper spire, often accentuated by a slightly adapical revolving stria; revolving sculpture below whorl periphery apparently rare or absent; on one specimen (not obviously developed on any others) with particularly well-developed sculpture, low elongate nodes are developed on the adapical spiral ridge and are expressed only on the last third of the last whorl of 5.5 whorl specimens; node axes appear to parallel the revolving ridge; on the basal surface of the same specimen, one rather wide nodular ridge is developed. Without umbilicus, umbilical area covered by a thickened, but not wide, columellar lip. Aperture broadly ovate, tending towards subquadrate depending on the degree to which the peripheral angularity is expressed on the outer lip; parietal lip not appreciably thinned; average aperture width-to-height ratio measured in plane of aperture 0.89 (1 SD = 0.04, min. = 0.83, max. = 0.99, n = 28, loc. = 4), measured in plane of coiling axis 1.20 (1 SD = 0.11, min. = 1.04, max. = 1.45, n = 28, loc. = 4), with a foreshortened change in aperture height of about 29%. Individual specimen measurements are given in Appendix 2 (for graphs of parameters, see Hartman, 1984).

**Etymology:** *codomorphus* (Greek), codono (kodon), bell; morpho (morphe), form, shape; the shape of a bell.

**Type Specimens:** Holotype, USNM-PAL 374602 (UND-JHH S0892); paratype-a USNM-PAL 374602 (UND-JHH S0200); paratype-b, USNM-PAL 374602 (UND-JHH S0202); paratype-c, USNM-PAL 374606 (UND-JHH S0894); paratype-d, UMPC 13610 (UND-JHH S0900); and paratype-e, UMPC 13611 (UND-JHH S0984) are all from Locality L0049 (see Type Locality and Appendix 1, Locality Register), Tongue River Member (after Vuke et al., 2003; Ludlow Member after Hartman, 1993; and suggested herein) of the Fort Union Formation, Fallon County, Montana.

**Chresonyms–Nomenclatural Summary**

1921 *Viviparus* (*Paludotrochus*) *trochiformis*: Cossmann, pl. V, figs. 1, 2.



**Figures 69–92.** *Viviparus codomorphus* new species. All specimens were coated with ammonium chloride for photography. **69–72.** UMPC 13610 [UND-JHH S0900], paratype-d (L0049). **69.** apertural. **70.** right lateral. **71.** Basal. **72.** abapertural. **73–76.** USNM-PAL 374603 [UND-JHH S0200], paratype-a (L0049). **73.** apertural. **74.** right lateral. **75.** basal. **76.** abapertural. **77–80.** USNM-PAL 374605 [UND-JHH S0894], paratype-c (L0049). **77.** apertural. **78.** right lateral. **79.** basal. **80.** abapertural. **81–84.** USNM-PAL 374602 [UND-JHH S0892], holotype (L0049). **81.** Apertural. **82.** right lateral. **83.** basal. **84.** abapertural. **85–88.** USNM-PAL 374604 [UND-JHH S0202], paratype-b (L0049). **85.** apertural. **86.** right lateral. **87.** basal. **88.** abapertural. **89–92.** UMPC 13611 [UND-JHH S0984], paratype-e (L4232). **89.** Apertural. **90.** right lateral. **91.** Basal. **92.** abapertural (note node development on basal periphery).

**Table 6.** *Viviparus codomorphus* Measurement Summary (in mm).[1]*

| MEASURE | N | MEAN | SD | MIN | MAX |
|---|---|---|---|---|---|
| #W | 22 | 5.3 | 0.2 | 4.5 | 5.8 |
| MSA | 22 | 62.6 | 3.6 | 58.0 | 71.0 |
| MSA | 50 | 61.2 | 3.6 | 53.5 | 71.0 |
| PHI | 28 | 23.1 | 3.0 | 13.1 | 27.6 |
| PWI | 28 | 20.8 | 2.4 | 13.0 | 24.7 |
| PSH1 | 30 | 6.4 | 1.1 | 3.1 | 8.1 |
| PBH | 30 | 16.8 | 2.1 | 10.1 | 19.9 |
| PSW1(MSW) | 22 | 17.8 | 1.8 | 11.8 | 20.9 |
| PSW1(MSW) | 50 | 18.4 | 1.7 | 11.8 | 22.4 |
| PSW2 | 50 | 11.1 | 1.2 | 6.6 | 13.6 |
| PSH2(MSH) | 22 | 13.3 | 1.8 | 7.4 | 15.4 |
| FAH | 28 | 15.0 | 1.7 | 9.6 | 18.1 |
| FAW | 28 | 13.4 | 1.6 | 8.3 | 16.1 |
| MSW/MSH | 22 | 1.4 | 0.1 | 1.2 | 1.6 |
| MSW/PSW2 | 50 | 1.7 | 0.1 | 1.5 | 1.8 |

*On specimens with ≥ 4.5 #W.

**Table 7.** Stratigraphic distribution of *Viviparus purgatorius* (examined specimens only).

| Stratigraphic unit State/Province | Localities (Lnos) |
|---|---|
| Tongue River Member, Fort Union Formation | |
| Montana | L1458? |
| Tullock (Bear) Member, Fort Union Formation | |
| Montana | L0010B, L0027?, L2951, L6460[1]* |
| Montana (Bear) | L0128? |
| Ravenscrag Formation | |
| Saskatchewan | L0209?, L0212?, L0214, L0217?, L0219, L0220, L0223?, L0224, L0225, L0229?, L0436 |

Code: ? = Questioned identification based on inadequate preservation.
*Type locality.

1984 *Viviparus codomorphus* Hartman, p. 331–340, pl, 3, figs. 9–32 (unpublished Ph.D. Dissertation).

**Previously Illustrated Specimens now assigned to *V. codomorphus***

Figured specimen, repository and locality not known.
  1921 Cossmann, pl. V, figs. 1, 2 (figured as *Viviparus trochiformis*).
Holotype, USNM-PAL 374602 (L0049)
  1984 Hartman, p. 575, pl, 3, figs. 21–24 (unpublished Ph.D. Dissertation) [figured as holotype].
Paratype, USNM-PAL 374603 (L0049)
  1984 Hartman, p. 575, pl, 3, figs. 13–16 (unpublished Ph.D. Dissertation) [figured as paratype-a].
Paratype, USNM-PAL 374604 (L0049)
  1984 Hartman, p. 575, pl, 3, figs. 25–28 (unpublished Ph.D. Dissertation) [figured as paratype-b].
Paratype, USNM-PAL 374605 (L0049)
  1984 Hartman, p. 575, pl, 3, figs. 17–20 (unpublished Ph.D. Dissertation) [figured as paratype-c].
Paratype, UMPC 13610 (L0049)
  1984 Hartman, p. 575, pl, 3, figs. 9–12 (unpublished Ph.D. Dissertation) [figured as paratype-d].
Paratype, UMPC 13611 (L4232)
  1984 Hartman, p. 575, pl, 3, figs. 29–32 (unpublished Ph.D. Dissertation) [figured as paratype-e].

**Type Locality (L0049):** Mr. Marshall E. Lambert, longtime curator of the Carter County Museum, Ekalaka, Montana, very kindly provided the necessary information and encouragement to relocate a locality he collected in August 1960, but for which he had only vague location information: “North of Baker” locality, 20 to 22 miles [32.2–35.5 km] north of Baker on Highway 7 on a conical butte. The locality was known to locals and the landowner, as it was originally excavated for chicken feed. The location is near the top of a very broad, largely grass-covered, and silcrete-boulder-strewn butte. The specimens were collected from a shallow pit at the north end, now nearly grassed over. The shell-bed thickness is only partially exposed, but is greater than 1-m thick when excavated and may extend over 60 m on a north-south trend.

The type series of *Viviparus codomorphus* was collected on July 8, 1977 by Hartman and J.A. Milske (UM) at an elevation of about 1027 m (3370 ft) from the Shell Butte locality (L0049), located near the center of the NE¼ NE¼ SW¼ sec. 13, T. 10 N., R. 59 E., Shell Butte Quad. (1981), Fallon County, Montana (Figure 93). The locality is mapped as Tongue River Member (Vuke et al., 2003), and is provisionally placed by the author at about 46 m (150 ft) above the top of the underlying Hell Creek Formation. The nearest available exposures of the Fort Union–Hell Creek formational contact are located about 2 km to the southwest. The exact stratigraphic placement of the locality depends on a more precise knowledge of the amount and change of dip in the strata as the beds flatten to the east on the east flank of the Cedar Creek Anticline. Stratigraphic studies by the author suggest that the locality may actually occur in the Ludlow Member (Hartman, 1993). Vuke et al. (1986) previously mapped the Shell Butte area as $FU_3$ and correlated it with the Slope Formation of North Dakota. Measured and study specimens were also collected on May 3, 1978, by Hartman, L. Doull, W. Hughes, L. Huntley, A. Krafft, E. Olson, A. Rautman, S. Russell, A. Snodgrass, and M. Timmerman; June 30, 1978, by Hartman and R.C. Holtzman; August 22, 1988, by Hartman; and July 6, 7, 1989, by Hartman, D.W. Krause, T. Kroeger, J. Hunter, G. Buckley, P.P. Lemelin, J.A. Quintana, and K.A. Zarembev.

**Reference Locality (L4232):** Locality L4232 (Brown Ranch locality) was discovered by the author July 28, 1982, and is one of the few continental molluscan localities with abundant snails and/or bivalves that form a shell-layer in the Ludlow Member of the Fort Union Formation in North Dakota. Locality L4232 was found to occur over a significant area of the School Section drainage (L4232a–e) at the same horizon between the

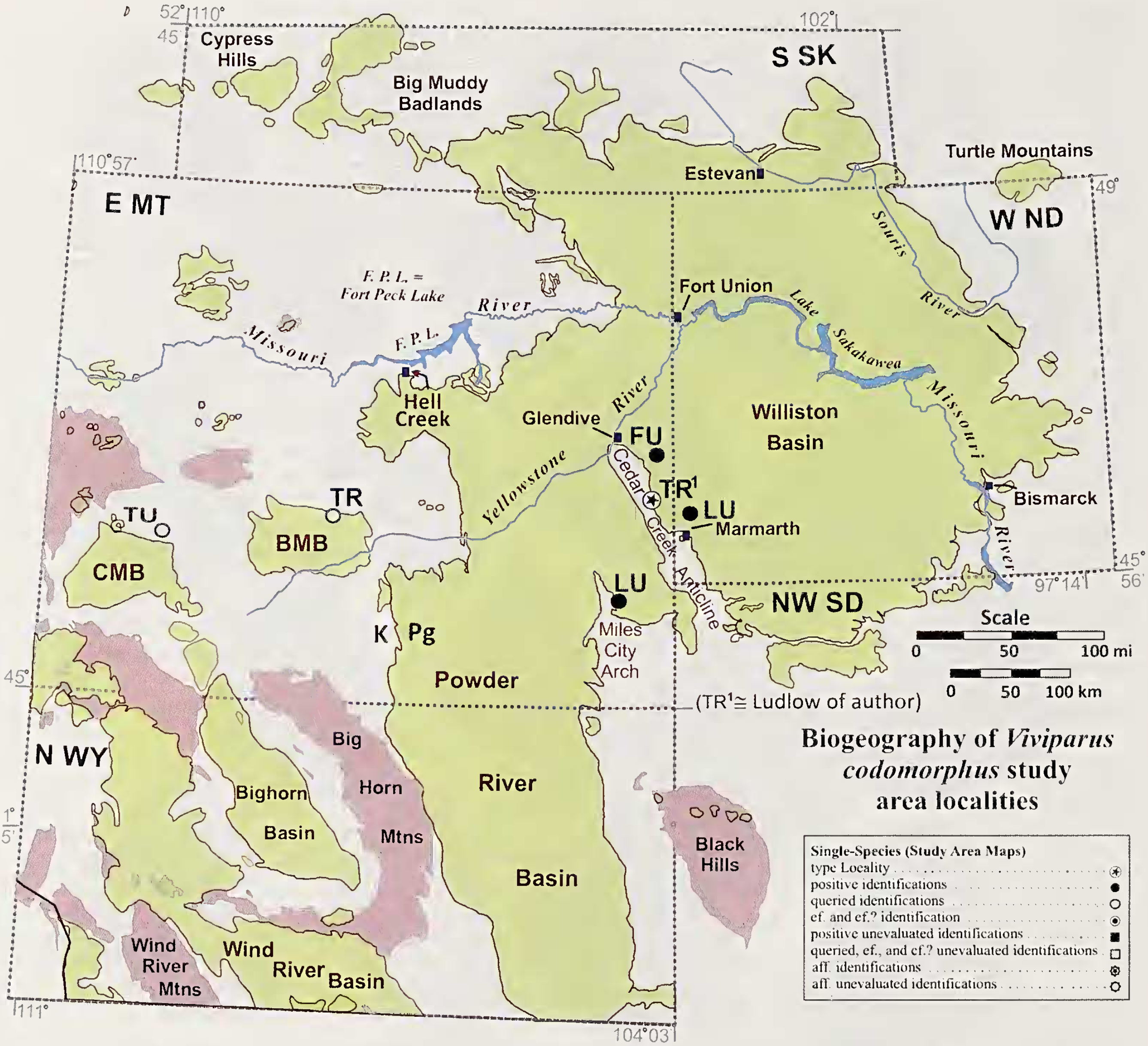


**Figure 93.** Biogeography of *Viviparus codomorphus* localities in the northern Great Plains of the USA (see Figure 24 for map notes).

"Lower and Upper Coal Pair" and the Boyce and Three V Tongues of the Cannonball Formation (Belt et al., 2005) in the upper part of the Ludlow Member (Slope Formation of others) on the Williams Lake Quad. (1979), Slope County, North Dakota. Measured and other specimens (Appendix 2) were collected at the time of discovery and on July 9, 1986, by Hartman and K.D. Enebo, and others; June 19, 1987, by Hartman, S.G. Strait, R. Crane; and June 23, 1988, by Hartman, D.W. Krause, T.C. Rae, and J.P. Hunter.

**General Distribution:** *Viviparus codomorphus* is presently known from just a few localities. These occurrences may be stratigraphically restricted to the upper part of the Ludlow Member of the Fort Union Formation or may range into the lowest part of the Tongue River Member (Figure 1; Table 7). All of the occurrences are adjacent to the Cedar Creek Anticline in far-western North Dakota (Slope County, L4232) and easternmost Montana (Carter and Fallon Counties, L0939 and L0049) to the Miles City Arch (Wibaux County, L0936), Montana (see Hartman, 1984, cross section F–8, L4232a, b). This limited distribution is mapped on Figure 93 (see Hartman, 1984, table 42 for cadastral data). Although amenable to bulk processing, no mammal teeth were found at L0049 after considerable effort and picking. The Brown Ranch local fauna includes mammal teeth from depauperate sites between the Boyce and Three V Tongues of the Cannonball Formation. A To1 or To2 is presently the best age estimate for this interval of the Ludlow Member (Hunter and Hartman, 2004). The age of the lowermost part of the Tongue River Member in Montana is uncertain, but is unlikely to be younger than Ti2 NALMA (see Figure 1).

**Discussion – *Viviparus (Paludotrochus) codomorphus*:** *Viviparus codomorphus* is the type species of the genus-group taxon *Paludotrochus* Cossmann. It was introduced to encompass the Late Cretaceous and Paleogene viviparid taxa in the Western Interior (specifically, the Laramie, *s.l.*, of Montana). Cossmann (1921) identified the type species as *Viviparus meeki* (then *V. trochiformis*). However, his description and illustrations clearly indicate that *Paludotrochus* was based on a taxon other than *V. meeki*. Cossmann's description and illustrated specimen are assignable to *V. codomorphus*, thereby recognizing this taxon as the type-species of *Paludotrochus*.

*Viviparus codomorphus* is a relatively uncommon if not rare taxon, but is locally abundant. *V. codomorphus* is presently known only from exposures near the Cedar Creek Anticline in easternmost Montana and westernmost North Dakota (Little Missouri River valley) (Figure 93). Specimens of this species are present in some of the museum collections examined during the course of this study (e.g., GSC general collection). Most museum labels record the following information: Montana (or Dawson County, Montana), Fort Union Formation, Wards. I suggest as a possibility that specimens of this species were acquired by Ward's Natural Science Establishment, Inc., Rochester, New York, and were sold to various institutions and maybe to Cossmann. Interestingly enough, the Ward's specimens were most often identified as *V. trochiformis* (= *V. meeki*).

## DISCUSSION

The Lancian viviparid fauna (Figures 1, 67) is distinctive, but was not recognized so by earlier paleontologists. In the Williston Basin, the Lancian fauna is largely characterized by *C. acroterion* and *V. thompsoni*. The former can occur by the thousands at some locations, while the latter is always relatively few in numbers. Other species of *Viviparus* are also present in the Lancian of Montana and North Dakota and await further treatment. They, too, are also relatively uncommon, with the North Dakota specimens preserved as sideritic steinkerns (Justham et al., 2007).

The Puercan (early Paleocene) viviparid fauna is based on relatively few localities, but additional records are available (with limited temporal control) from studies in the Bear Formation of the Crazy Mountains Basin, Montana (Hartman, 1989). Bear Formation localities are interpreted as lower Paleocene based on mammalian studies by Buckley (Hartman et al., 1989; Buckley, 1995). The discovery of the Racetrack Ridge locality confirmed the distinctiveness of the *Viviparus purgatorius*, and provided an additional local fauna for comparison. Other localities of importance include Purgatory Hill (L0010) in Montana and Pine Cree Park (L0437) in Cypress Hills, southwestern Saskatchewan, from the basal strata of the Ravenscrag Formation. All of the localities below the Pine Cree Locality are interpreted to be early Paleocene. Locality L0220 occurs in the lowermost strata of the Ravenscrag Formation and is probably the oldest Paleocene locality of this report.

Few Torrejonian viviparid-bearing localities are known from the Williston Basin (Hartman, 1984). The two best-known localities (L0049 and L4232) provide very well preserved specimens of *Viviparus codomorphus* and associated fossils, indicating their distinctiveness. Subsequent work has found a large number of Torrejonian-age localities in the Crazy Mountains Basin. Although most material is plastically deformed, viviparid diversity appears to remain low although specimens are common. Possible occurrences of *Viviparus codomorphus* in the lowermost part of the Tongue River Member may indicate an upper Torrejonian or lower Tiffanian age, depending on location. In Saskatchewan, in the valley of the Big Muddy, the age of the Ravenscrag Formation may be at least mid Paleocene (Ti2) (Sweet, 1978; Craig Scott, Geological Survey of Canada, verbal communication, 2014).

Three new species viviparid species herald the species and evolution to follow in their respective genera. All three species appear to have existed for about the same duration (3 million years). *Campeloma acroterion* is beginning part of a succession of three species of *Campeloma* over about a 12 million-year period that may be traced back to *C. vetula* (Meek and Hayden) of the Campanian Judith River Formation of north-central Montana. *Viviparus purgatorius* and *V. codomorphus* may or may not give rise to the radiation of *Viviparus* taxa seen in the northern Great Plains later in the Paleocene. Viviparid taxa are a common if not dominant macrogastropod element of primarily fluvial faunas during the changes in sea level effecting Laramidia during the Late Cretaceous. The taxa have a similar, if maybe reduced, overall disparity and diversity in early and mid Paleocene faunas with multiple incursions of the Cannonball Sea. With regression of the Cannonball Sea in the early late Paleocene (Hartman et al., 1999), viviparids radiate, becoming far more numerous, diverse, and morphologically variable until the end of the Laramide Orogeny (about mid Eocene). The species introduced here, along with others that may exist, foreshadow the success of *Viviparus* in the late Paleocene in North America.

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